Chapter XL
Fault Tolerant Topology Design for Ad Hoc and Sensor Networks

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ABSTRACT

Fault tolerance is one of the premier system design desiderata in wireless ad hoc and sensor networks. It is crucial to have a certain level of fault tolerance in most of ad hoc and sensor applications, especially for those used in surveillance, security, and disaster relief. In addition, several network security schemes require the underlying topology provide fault tolerance. In this chapter, we will review various fault tolerant techniques used in topology design for ad hoc and sensor networks, including those for power control, topology control, and sensor coverage.

INTRODUCTION

With great potentials in a large number of application fields, ad hoc and sensor networks have been undergoing a revolution that promises a significant impact on society. Unlike traditional fixed infrastructure networks, there are no centralized controls over wireless *ad hoc* networks, which consist of a collection of devices equipped with wireless communication and networking capability. Any communication and network service in ad hoc networks is done in a self-organized and decentralized manner. Usually connections are multihop routed via intermediate nodes to enable communication between nodes without a direct link. A wireless sensor network is a network of small, wirelessly communicating nodes where each node is equipped with computation, communication, and sensing devices. These nodes usually form a self-organized ad hoc network, observe the physical space around them, and measure some physical signals or detect various phenomena of interest. Ad hoc and sensor networks are widely deployed for environment monitoring, biomedical observation, surveillance, security, disaster relief, and so on.

Ad hoc and sensor networks trigger many challenging research problems, as they intrinsically have many special characteristics and unavoidable limitations, compared with other wired or wireless networks. An important requirement of ad hoc and sensor networks is that they should be self-organizing, that is, transmission ranges and data paths are dynamically restructured with changing topology. Energy conservation and network performance are probably the most critical issues in ad hoc and sensor networks, since wireless devices (such as tiny sensor nodes in sensor networks) are usually powered by batteries only and have limited computing capability and memory. Topology control and power control are two primary techniques with respect to energy-efficiency in ad hoc and sensor networks.

The topology control technique is to let each wireless device locally select certain neighbors for communication, while maintaining a topology that can support energy efficient routing and improve the overall network performance. Unlike traditional wired networks and cellular wireless networks, mobile devices are often moving during the communication, which could change the network topology in some extent. Hence it is more challenging to design a topology control algorithm for ad hoc and sensor networks. The power control technique is to control the network topology by adjusting the wireless device's transmission range. Reducing the transmission range can save the power consumption at each node and reduce the signal interference among neighbors, but it may hurt the connectivity of the induced topology. Power control tries to minimize the power consumption used by all nodes while maintaining a topology that is connected and has certain desired properties such as fault tolerance.

Although fault tolerance has been studied for several decades in computer and VLSI systems, limited resources on small devices, lack of centralized control, and high mobility make fault-tolerance much harder to achieve in ad hoc and sensor networks. One key characteristic of such networks is that node and link failure is an event of non-negligibility, in some cases even as a regular or common event. This is particularly the case in sensor networks where the equipment is restricted to a minimum due to limitations in cost and weight. First of all, battery driven sensor nodes may stop working because they run out of energy supply. Second, the shared wireless medium is inherently less stable than wired media. This situation results in more packet losses and lower throughput. Third, sensor networks often operate in potentially hostile or at least harsh and unconditioned environments. Tiny sensor devices with limited security techniques are usually vulnerable from various attacks. Another aspect that has an influence on the required degree of redundancy and fault-tolerance is mobility, which is a key issue in ad hoc networks. Therefore, reliability and fault-tolerance are emerging as premier and crucial system design desiderata in ad hoc and sensor networks. In addition, fault-tolerance design is also one of basic components in ad hoc and sensor network security.

Fault tolerance strongly depends on the network connectivity. To make fault tolerance possible, first of all, the underlying network topology must be k-connected for some $k > 1$, that is, given any pair of wireless devices, at least k disjoint paths are needed to connect them. With k-connectivity, the network can survive k-1 node/link failures. Traditional topology control or power control solutions cannot cope with those fault-tolerance requirements, since fault-tolerance is usually sacrificed for power efficiency. In order to be power efficient, topology control and power control algorithms try to reduce the number of links and thereby reduce the redundancy available for tolerating node and link failures. On the other hand, to achieve fault-tolerance, existing algorithms usually sacrifice power efficiency concern. Thus, topology design for ad hoc and sensor networks needs to consider both power efficiency and fault-tolerance.

This chapter is focused on fault tolerant topology design for ad hoc and sensor networks. In the second section, fault tolerant techniques used in power control protocols (such as power assignment and critical transmission range) are reviewed. In the third section, we survey fault tolerant design in topology control, that is, how to design fault tolerant geometric or hierarchical structures. In the